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# VIBRATION TYPE ANGULAR VELOCITY METER
[Shindo-shiki kaku-sokudokei]

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Claims

1. A vibration type angular velocity meter characterized by comprising a vibrator equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting section of the aforementioned vibrator, an excitation means for wobbling the aforementioned mass member of the aforementioned vibrator, a frequency detection means for detecting the frequency of the aforementioned wobbling, a self-excitation circuit for wobbling the aforementioned vibrator, and an arithmetic part for computing an angular velocity of the aforementioned vibrator in accordance with a change in the frequency of the aforementioned vibrator.

2. A vibration type angular velocity meter characterized by comprising multiple vibrators [each] equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting sections of the aforementioned vibrators, an excitation means for wobbling at least one of the aforementioned vibrators while wobbling the other vibrator in the opposite direction or vibrating it in a bending fashion in a linear direction, a self-excitation circuit for wobbling the aforementioned vibrators, and an arithmetic part that computes the difference between the frequencies of the aforementioned vibrators so as to compute the levels and the directions of the angular velocities of the aforementioned vibrators.

Detailed explanation of the invention

Industrial application field

The present invention pertains to a vibration type angular velocity meter utilized for obtaining an attitude control signal for such a moving body as an aircraft.

Conventional example

A vibration type angular velocity meter utilizing Coriolis forces is often formed into the shape of a tuning-fork because a high level can be attained for Ω so as to reduce the driving energy, and a high level of sensitivity can be achieved.

Figure 8 shows the structure of a tuning-fork-shaped vibration type angular velocity meter known through Japanese Kokai Patent Application No. Sho 35[1960]-3692 gazette, for example. 1a and 1b represent forks facing input axis Z of angular velocity Ω; and 2a and 2b represent piezoelectric elements pressure-welded to said forks, whereby they are excited using an external AC driving power supply in order to vibrate forks 1a and 1b closer to or away from axis Z in the directions indicated by ω, that is, to generate in-plane vibrations.

Frequency of said vibrations resonates with the characteristic frequencies of forks 1a and 1b, and a /2*
large amplitude is generated using a small driving energy.

When angular velocity Ω is input to axis Z, a Coriolis force, that is, a torsional torque, with the same frequency as the driving frequency and an amplitude proportional to Ω is generated in the direction orthogonal to the directions indicated by ω as indicated by A and B or A' and B'. 3 represents a shaft used to detect said torque, wherein it is connected to the bottom of the tuning-fork at one end via vibration-absorbing member 4 while fixed to base member 5 at the other end. 3a represents a torque transfer lever that is used to apply a vibrating torsional torque to piezoelectric element 6 pressure-welded to pole 5a provided on the base member and take the resulting converted electric signal to the outside.

Here, characteristic frequency of the part that includes shaft 3 and base member 5 while in a primary mode is selected in such a manner that it becomes equal to the characteristic frequency of the aforementioned in-plane vibrations of the tuning-fork while in the primary mode, and the vibrations

created by the weak Coriolis force are amplified by means of resonance before they are taken to the outside.

Problems to be solved by the invention

However, as described above, when the characteristic frequency at the driving part and the characteristic frequency at the detection part are the same, vibrations of the driving part affect the detection part, and detection of the torque generated by the weak Coriolis force becomes difficult. Thus, absorber 4 that absorbs the vibration energy on the driving side becomes essential, so that the overall structure becomes complicated.

In addition, because a piezoelectric element was used to detect the weak Coriolis force, there were problems in terms of fluctuations in the stability and the sensitivity at the zero position.

The present invention was made in the light of the aforementioned problems of the conventional technology, and its purpose is to realize a compact high-precision angular velocity meter through the utilization of a novel configuration for detecting the angular velocity based on changes in the characteristic frequency.

Means to solve the problems

In order to solve the aforementioned problems, the first invention comprises a vibrator equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting section of the aforementioned vibrator, an excitation means for wobbling the aforementioned mass member of the aforementioned vibrator, a frequency detection means for detecting the frequency of the aforementioned wobbling, a self-excitation circuit for wobbling the

* [Numbers in right margin indicate pagination of the original text.]

aforementioned vibrator, and an arithmetic operation part for computing an angular velocity of the aforementioned vibrator in accordance with a change in the frequency of the aforementioned vibrator.

In order to solve the aforementioned problems, the second invention comprises multiple vibrators [each] equipped with a wobbling mass member and a supporting section that supports said mass member elastically, a case for securing the aforementioned supporting sections of the aforementioned vibrators, an excitation means for wobbling at least one of the aforementioned vibrators while wobbling the other vibrator in the opposite direction or vibrating it in a bending fashion in a linear direction, a self-excitation circuit for wobbling the aforementioned vibrators, and an arithmetic operation part that computes the difference between the frequencies of the aforementioned vibrators so as to compute the levels and the directions of the angular velocities of the aforementioned vibrators.

Application examples

The first invention will be explained below using figures.

Figure 1 are perspective views showing the configuration of the cardinal part of an application example of the present invention; wherein, (a) shows a single body of vibrator, and (b) shows a partially cut-off overall view except for an arithmetic operation part.

Vibrator <u>20</u> is configured with wobbling mass member 21 and supporting section 22 that supports mass member 21, and it is equipped with case 23 for securing vibrator 20. A constantly elastic member is used as the material of vibrator 20 in order to reduce temperature-dependency of the characteristic bending frequency of the vibrator. Mass member 21 is cylindrical, supporting section 22 is in the shape of a rod with a round cross section, and they constitute a cantilever beam. Primary characteristic bending frequency $\omega_0$ of the cantilever beam is given as

$$\omega_0 = \left(\frac{1.8751}{\ell}\right)^{2} \sqrt{\frac{EIg}{\gamma A}} \qquad (1)$$

Here, l represents length of supporting section 22, I represents geometric moment of inertia of the beam, A represents cross-sectional area of the beam, g represents gravitational acceleration, $\gamma$ represents weight of the beam material per a unit volume, and E represents longitudinal elastic modulus of the beam material. Mass member 21 reduces characteristic bending frequency $\omega_0$ of vibrator 20. When characteristic bending frequency $\omega_0$ is low, the frequency of the wobbling of vibrator 20 becomes lower, which is advantageous when detecting changes in the wobbling frequency attributable to the angular velocity.

Characteristic bending vibration modes of said vibrator come in 2 independent modes; namely, direction of line segment B-B* for characteristic vibrations at a low frequency and direction of line segment C-C* for characteristic vibrations at a high frequency. However, the vibration type angular /3
velocity meter is used in such a manner that the characteristic frequencies of said 2 modes are adjusted to match with each other.

Through hole is created at the center of electrode support 31, and a mass member is placed inside of said through hole with a small gap. Electrode support 31 is usually configured using an insulation material, such as glass or ceramics; and electrodes 34a, 34b, 35a, and 35b are formed on it by means of sputtering and plating. Spacer 32 is placed between case 23 and electrode support 31, and it is used to adjust the position of counter surface 33 that faces mass member 21 placed in the through hole of the electrode support. Although 4 electrodes are formed on electrode support 31, detection electrode 35b is not shown in Figure 1 (b). As for the electrodes, 2 driving electrodes 34a and 34b and 2 detection electrodes 35a and 35b are formed in said order, and they are configured in such a manner that the 2 characteristic modes of vibrator 20 can be detected. The 4 electrodes are shaped so as to connect counter surface 33, that faces mass member 21, with terminals that are provided on outer cylindrical surface 36 for connecting with an excitation circuit and a detection circuit not shown. Said terminals are configured with the inclusion of hermetic terminals.

Figure 2 is a block diagram showing configurations of an excitation means and a frequency detection means. A self-excitation circuit is configured using the frequency detection means and a vibrator.

Detection electrodes 35a and 35b and mass member 21 constitute a capacitance. Here, vibrations of mass member 21 are taken out by capacitance detection circuit 36 in the form of changes in the capacitance. Said capacitance detection circuit 36 is configured with the inclusion of a bridge circuit, for example. Filter 37 extracts only the frequency that is equivalent to the primary characteristic bending frequency of vibrator 20 out of a signal from capacitance detection circuit 36. Phase shifter 38 decides the difference between the phase of the vibrations of mass 21 and that of automatic gain control amplification circuit (will be referred to as AGC circuit, hereinafter) 39 to be supplied to driving electrode 34a. Said phase difference is used to decide the shape of rotational movements and the level of sensitivity regarding changes in the rotational movement frequency with respect to the angular velocity.

AGC circuit 39 oscillates at fixed voltage $E_S$ that is decided by reference voltage supply unit 42. An AC voltage from AGC circuit 39 is sent through rectifier 40, converted into DC voltage $E_V$, and compared with reference voltage $E_S$ at integrator 41; whereby, the oscillation by AGC 39 is increased if DC voltage $E_V$ is low, and the oscillation by AGC circuit 39 is reduced as DC voltage $E_V$ becomes higher, so that the oscillation by AGC circuit 39 can be kept constant after all.

The AC voltage from AGC circuit 39 is combined with DC voltage $E_b$ from DC power supply 44 and supplied to driving electrode 34a. DC voltage $E_b$ is set in such a manner that it changes only in the positive voltage region when combined with the AC voltage. An AC voltage, that is obtained by shifting the phase for roughly 90˚ at phase shifter 43 and adding a DC voltage from DC power supply 44 to it, is supplied to the other driving electrode 34b. Whether vibrator 20 wobbles in the clockwise (will be referred to as CW, hereinafter) or counterclockwise (will be referred to as CCW, hereinafter) is decided depending on whether the 90˚ phase shifting is set forward or backward.

On the other hand, the AC voltage from AGC circuit 39 is supplied also to phase difference detection circuit 46 that constitutes an arithmetic operation part for computing the level and the direction of angular velocity $\Omega$ that is applied to vibrator 20. Phase difference detection circuit 46 detects the phase difference between a signal from reference frequency generation means 45, such as a reference vibrator that generates a fixed frequency irrespective of angular velocity $\Omega$, and a signal from AGC circuit 39 at frequency $\omega_0$ that corresponds to the frequency of the wobbling when angular velocity $\Omega$ of vibrator 20 is zero. Because said phase output becomes discontinuous at every 360°, and the sensitivity of the vibrator never reaches the logical sensitivity of 1, which will be described in detail below, computer 47 that corrects them and displays rotating angle $\overline{\varphi}$.

Principles of the operations of the device configure in said manner will be explained next. Figure 3 shows a model in which vibrator 20 is simplified. Because vibrator 20 is adjusted in such a manner that the characteristic bending frequencies in all directions becomes the same, spring constant k, mass M, and the frequency of the rotational movements can be described using a system that operates at the same frequency as characteristic bending frequency $\omega_0$ of vibrator 20 as shown in Figure 3. Here, assuming that rotational movements are circular in shape, mass M moves on a circular orbit with the radius of r and the center at point 0. At this time, because the centrifugal force and the centripetal force generated by spring k almost balance out,

$$Mr\omega_0^2 = rk \qquad (2)$$

comes into effect. Here, angular frequency $\omega_0$ of the vibrations matches the characteristic bending frequency of the vibrator, so it can be given by

$$\omega_0 = \sqrt{k/M} \qquad (3)$$ /4

Next, a case in which angular velocity $\Omega$ is applied around axis Z, that is formed at the right angle with respect to the circular orbit of mass M that runs through point 0, in the system shown in Figure 3

will be considered. When angular velocity $\omega$ of mass M, drifting velocity v of mass M, and the centripetal force that are observed in the system rotating at angular velocity $\Omega$ are balanced out,

$rk = Mr\omega^2 + Mr\Omega^2 + 2Mv\Omega$ (4)

comes into effect. Here, while paying attention to

$v = r\omega$,

when Formula (2) and Formula (4) are compared,

$Mr\omega_0{}^2 = Mr\,(\omega + \Omega)^2$ (5)

or

$\Omega + \omega_0 - \omega$ (6)

results.

Therefore, when a deviation from rotational movement frequency $\omega$ is observed with reference to the same frequency as $\omega_0$, angular velocity $\Omega$ acted upon vibrator 20 can be found. Here, the rotational movement corresponds to the wobbling of vibrator 20.

In addition, its operations as an integrating gyro can be obtained easily by integrating Formula (6) with respect to time t. That is, assuming that the rotational angle of vibrator 20 is denoted as $\overline{\varphi}$,

$$\begin{aligned} \overline{\varphi} &= \int^t \Omega(t)\, dt \\ &= \int^t (\omega_0 - \omega)\, dt \qquad (7) \end{aligned}$$

comes into effect. That is, when reference frequency $\omega_0$ and rotational movement frequency $\omega$ of reference frequency generation means 45 are supplied to phase difference detection circuit 46 to detect the deviation, although the value indicated by phase difference detection circuit 46 when angular velocity $\Omega$ becomes zero is fixed and does not change, the value indicated changes when angular velocity $\Omega$ is applied, so that the phase changes to the extent of rotational angle $\overline{\varphi}$.

Figure 4 shows an example when the angular velocity is measured using the vibration type angular velocity meter explained in the aforementioned application example. The vertical axis indicates phase difference (unit is °) as indicated by phase difference detection circuit 46, and the horizontal axis represents a time axis. Because the wobbling frequency of vibrator 20 is 348.881 (Hz), reference frequency $\omega_0$ is also 348.881 (Hz). Rotational angle $\overline{\varphi}$ of vibrator 20 is added at every 30 ± 2°, and its angular velocity is 5 (°/sec.). At this time, the phase difference output is 0.98 time of rotational angle $\overline{\varphi}$.

As shown in Formula (6), the reasons as to why the sensitivity never become 1.00 time is that the orbit of mass M is not completely round, and the characteristic frequencies of the 2 characteristic bending modes of the vibrator do not match completely.

Figure 5 is a perspective view showing the configuration of another application example of the present invention, wherein a single body of vibrator is shown.

Mass member 21 is fixed to case 23 via supporting sections 22a and 22b that are arranged on a straight line. Mass member 21 is in the shape of a cylinder with a large diameter; and supporting sections 22a and 22b are formed into cylinders with a small diameter, and their center lines are aligned with each other. Case 23 is equipped with fixation parts 23a and 23b for securing supporting sections 22a and 22b and wall bodies 23c and 23d for supporting fixation parts 23a and 23b. Because wall bodies 23c and 23d are configured sufficiently larger than the cross-sectional areas supporting sections 22a and 22b, they are highly rigid.

Operations of the device configured in said manner will be explained next. The vibrator shown in Figure 1 (a) had a problem that, because the weight of mass member 21 acted upon supporting section 22 changed depending on postures of vibrator 20, the characteristic bending frequency of the vibrator was changed as the axial force of supporting section 22 changed. (While the changes in the characteristic frequency attributable to this factor is 1 ppm or less, for example, because the lower limit

of the angular velocity to be detected of the characteristic frequency of approximately 350 (Hz) is 0.01 (°/sec.), the frequency needs to have the stability level of 0.08 ppm.)

In the case of the vibrator pertaining to Figure 5, because mass 21 is supported using 2 supporting sections 22a and 22b, the axial force acted upon supporting sections 22a and 22b never changes regardless of the postures of the vibrator, so that the characteristic bending frequency of the vibrator never changes.

A configuration in which supporting sections 22a and 22b are formed into the shape of a thin line, and mass member 21 is supported while a tension is applied to them may be adopted also. The point that the tension applied to supporting sections 22a and 22b remains constant regardless of the postures of the vibrator is no different from the vibrator shown in Figure 5.

Furthermore, the first invention is not restricted to the aforementioned application example; that is, although a case involving a round orbit for the wobbling movements was shown, an oval shape may be used. In addition, although the 2 characteristic bending frequencies of vibrator 2 matched perfectly, it is also feasible that 1/Q (Q is a quantity indicating the level of resonance of the vibrator system) of characteristic bending frequency $\omega_0$ of said vibrator may be set to $\Delta\omega$, and the difference between the 2 /5
characteristic bending frequencies is set within several times of $\Delta\omega$. The reason is that the vibrator can wobble at a sufficient amplitude even though the 2 characteristic bending frequencies may not match perfectly.

In addition, although the excitation means was driven electrostatically in the application example, the vibrator may be made of a magnetic material and driven electromagnetically, and a piezoelectric substance may be adhered to the vibrator so as to excite the vibrator.

In addition, although the frequency detection means detected the vibrations of the vibrator based on changes in the capacitance in the application example, the vibrator may be made of a magnetic body so as to utilize inductance to this end, or some other displacement detection means may be utilized. In

addition, the rotational movements of the vibrator may be detected by detecting the stress generated at the supporting section of the vibrator.

In addition, although the arithmetic operation part utilizes the same reference frequency as that obtained when the angular velocity is zero in order to detect changes in the rotational movement frequency, a highly stable reference clock with a high frequency may be utilized to detect changes in the rotational movement frequency.

Figure 6 and Figure 7 are perspective views showing configurations of application examples of the second invention, wherein a single body of vibrator is shown.

In Figure 6, 2 units of the vibrator pertaining to Figure 1 (a) are provided on case 23 on straight line Z. Mass member 21a provided at one end rotates CW, and the other mass member 21b rotates CCW.

In Figure 7, 2 units of the vibrator pertaining to Figure 1 (a) are provided on case 23 around the centers of parallel straight lines $Z_1$ and $Z_2$. Mass member 21a provided at one side rotates CW, and the other mass member 21b rotates CCW.

Operating principles of the devices configured in said manners will be explained next. Assuming that angular velocity $\Omega$ is CW, Formula (6) can be expressed as

$$\Omega_{CW} = \omega_{0CW} - \omega_{CW} \qquad (8)$$

for one of the vibrators, and it can be expressed as

$$\Omega_{CW} = -(\omega_{0CCW} - \omega_{CCW}) \qquad (9)$$

for the other. Therefore, when they are used differentially, changes in the rotational movement frequencies with respect to angular velocities $\Omega$ of the vibrators, that is their sensitivities, can be doubled; and that changes in characteristic bending frequencies $\omega_0$ attributable to posture errors and changes in temperature can be erased effectively.

Here, one of the vibrators pertaining to Figure 6 and Figure 7 may be engaged in linear bending vibrations so as to obtain reference frequency $\omega_0$ while the other vibrator is engaged in rotational movements so as to detect angular velocity $\Omega$.

Effects of the invention

As described above, the first invention has the following characteristics. First, because the case and the supporting section can be formed as a single structure, the structure of the vibrator can be simplified. In addition, because the output is the frequency, it can be digitally processed easily and incorporated into a computer easily.

With the second invention, because changes in the characteristic bending frequencies attributable to posture errors and changes in temperature can be erased effectively, a high-precision vibration type angular velocity meter can be realized.

Brief description of the figures

Figure 1 are perspective views showing the configuration of the cardinal part of an application example of the first invention; wherein, (a) shows a single body of vibrator, and (b) shows the overall view except for an arithmetic operation part. Figure 2 is a block diagram showing configurations of an excitation means and a frequency detection means. Figure 3 shows a model for explaining the operating principles. Figure 4 shows an example of measured angular velocity. Figure 5 shows another application example of the first invention. Figure 6 and Figure 7 are perspective views showing configurations of application examples of the second invention. Figure 8 is a diagram showing a conventional device configuration.

20 … vibrator; 21 … mass; 22 … supporting section; 23 … case; 31 … electrode support; 34a, 34b … driving electrode; 35a … detection electrode; 36 … capacitance detection circuit; 45 … reference frequency; 46 … phase difference detection circuit.

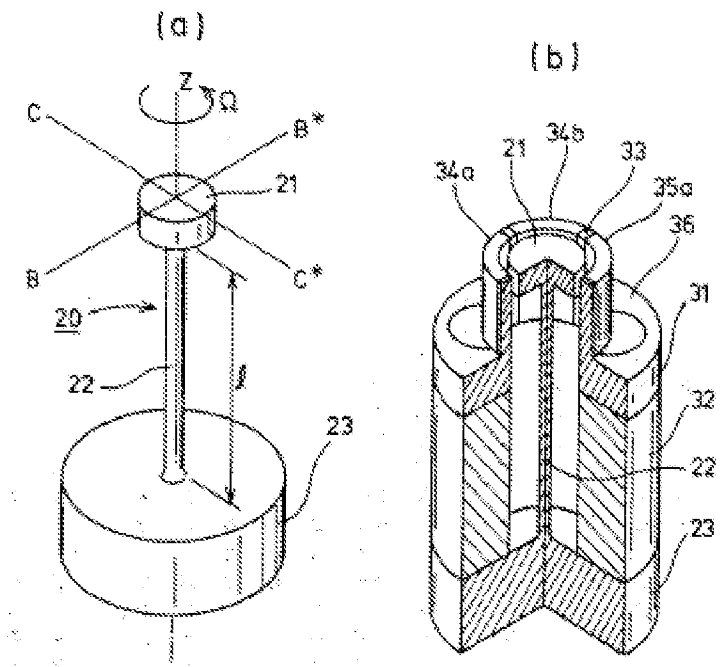


Figure 1

Key:

| | |
|---|---|
| 20 | vibrator |
| 21 | mass member |
| 22 | supporting section |
| 23 | case |
| 31 | electrode support |
| 32 | spacer |
| 33 | counter surface |
| 34a, 34b | driving electrode |

35a detection electrode

36 outer cylindrical surface

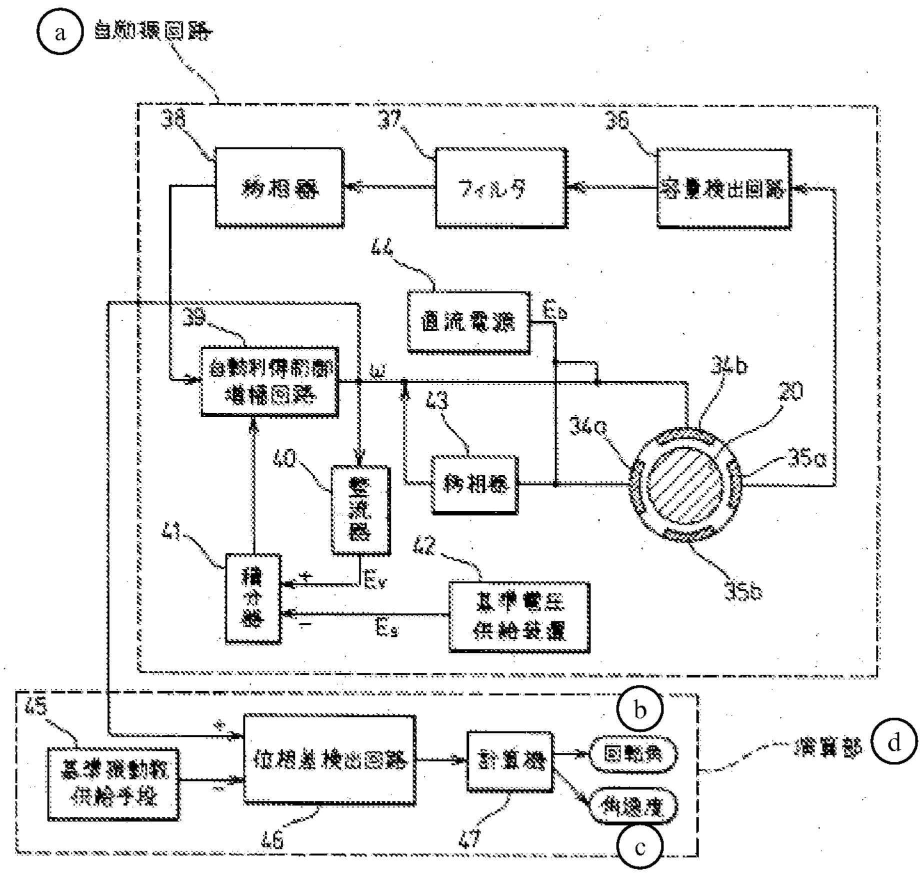


Figure 2

Key: a self-excitation circuit

b rotational angle

c angular velocity

d arithmetic operation part

36 capacitance detection circuit

37 filter

38, 43 phase shifter

39 automatic gain control amplification circuit

40 rectifier

41 integrator

42 reference voltage supply unit

44 DC power supply

45 reference frequency supply [sic.; generation] means

46 phase difference detection circuit

47 computer

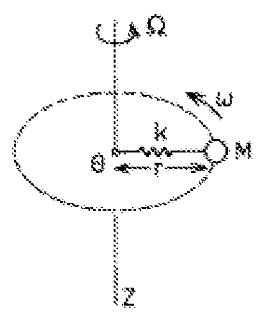


Figure 3

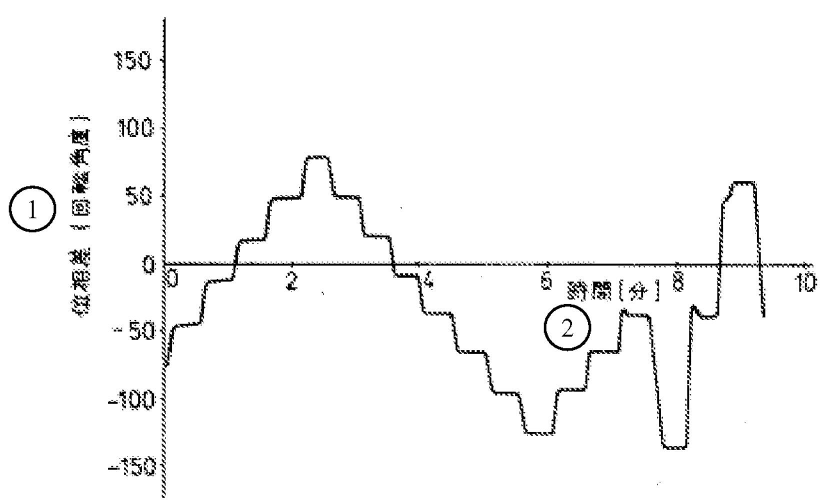


Figure 4

Key: 1 phase difference

2 time (min.)

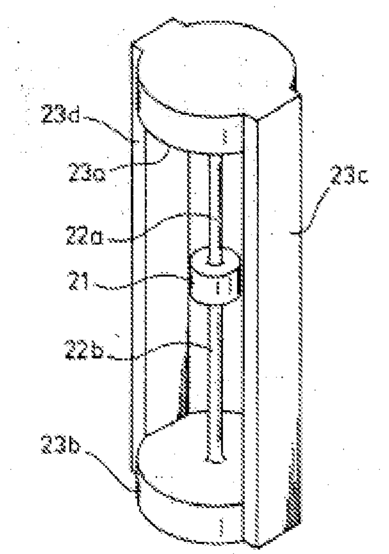


Figure 5

Key: 21 mass member

22a, 22b supporting section

23 case

23a, 23b fixation part

23c, 23d wall body

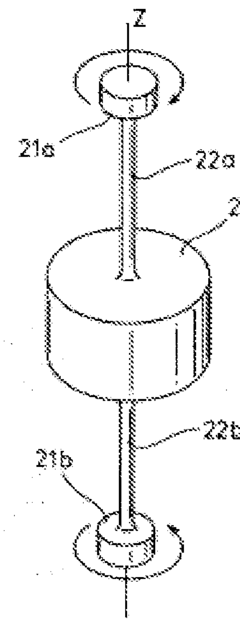


Figure 6

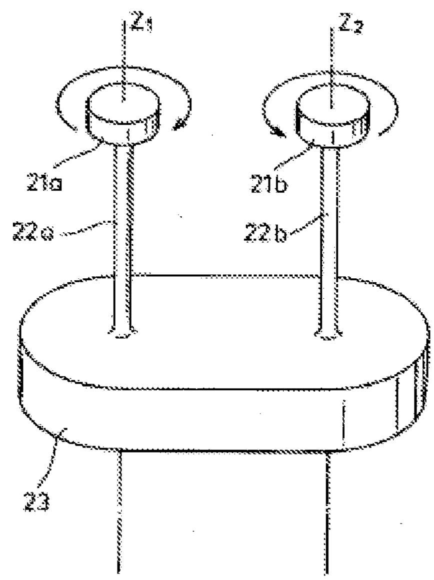


Figure 7

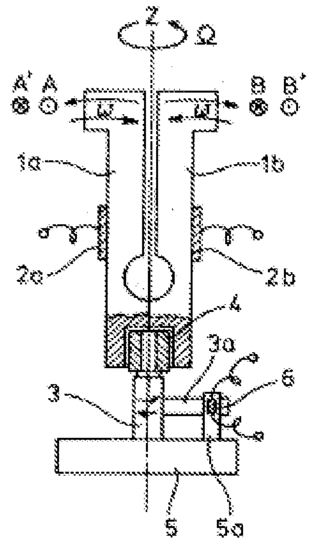


Figure 8